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Research Article

Assessing Domain Specificity in the Measurement of Mathematics Calculation Anxiety

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An online, cross-sectional approach was taken, including an opportunity sample of 160 undergraduate students from a university in the Midlands, UK. Exploratory factor analysis indicated a parsimonious, four-factor solution: *abstract maths anxiety*, *statistics probability anxiety*, *statistics calculation anxiety*, and *numerical calculation anxiety*. The results support previous evidence for the existence of a separate "numerical anxiety" or "arithmetic computation" anxiety component of maths anxiety and also support the existence of anxiety that is specific to more abstract maths. This is the first study to consider the multidimensionality of maths anxiety at the level of the calculation type. The 26-item Maths Calculation Anxiety Scale appears to be a useful measurement tool in the context of maths calculation specifically.

1. Introduction

Recent data from the Organisation for Economic Co-operation and Development (OECD), which includes data from several countries, highlighted that 59% of students often worry that it will be difficult for them in mathematics (maths) classes [1]. Meta-analytic work has shown how maths anxiety is related to avoidance of maths study and intention to take further maths courses [2]. It is therefore unsurprising that higher levels of maths anxiety have been shown to be related to lower maths achievement [3]. There is also a growing body of evidence to suggest that maths anxiety is linked to physiological [4] and neurological activity [5–7], and it appears that maths has a special affective component, demonstrating links with maths achievement that are distinct from other forms of anxiety and more general academic achievement [8]. Furthermore, there are varying theoretical models concerning the relationship between maths anxiety and performance, including the deficit theory, debilitating anxiety model, and reciprocal theory [9]. Together, there is empirical evidence to suggest that maths anxiety is a pervasive issue to be addressed.

Several definitions of maths anxiety have been proposed over the years, e.g., "the panic, helplessness, paralysis and mental disorganisation that arises among some people when they are required to solve a mathematical problem" [10] and the "feeling of tension, apprehension or even dread, that interferes with the ordinary manipulation of numbers and the solving of mathematical problems" [11]. Such definitions make assumptions regarding what constitutes "maths", with the latter alluding to the role of actual numerical calculation.

Empirically measuring anxiety pertaining to numbers began in 1958 with the Numerical Anxiety Scale [12]. Since then several self-report scales for measuring maths anxiety have been published [13–17]. These scales highlight the multidimensional nature of maths anxiety, often indicating how anxiety may differ according to the context in which an individual is exposed to maths. Such contexts include, for example, the classroom, a shop, calculating a budget, or even watching others attempt a maths problem. Through factor analysis of maths anxiety scales, factors that relate to context, rather than the maths problems themselves, have been identified [15–18]. In contrast, previous authors have identified broader subscales concerning anxiety pertaining to calculation, e.g., problem-solving anxiety [19], numerical anxiety [20, 21], arithmetic computation anxiety [22], numerical task anxiety [23, 24], and everyday numerical anxiety and problem-solving anxiety [25]. However, it is important to note that many maths anxiety scales are derivatives of the original Mathematics Anxiety Rating Scale [13] and so focus on context.

Given the contrasting findings already in existence, it would be interesting to better understand the dimensionality of maths anxiety. To date, no study has fully investigated the way in which individuals may experience anxiety when attempting specific forms of maths, although one study [26] identified a distinct factor of maths anxiety, labelled abstraction anxiety, which is thought to pertain to anxiety towards more abstract forms of maths, such as algebra. The core areas covered within General Certificate of Secondary Education (GCSE) maths afford a useful way of studying dimensionality, namely statistics and number, number and algebra, and geometry and algebra. The GCSE is a level that the vast majority of 14- to 16-year-old UK children are required to study, with assessments taken at ages 15–16 years. Perhaps more importantly, as the GCSE-level maths covers three key areas, a fuller understanding of the nature of maths anxiety in terms of anxiety towards the type of maths is needed. This may potentially help with identification of individuals that require support with anxiety that is specific to certain types of calculation. Further, it has been argued that maths anxiety research should begin to focus on the concept of flexibility in mathematical problem solving [27]. It is unknown whether anxiety differs as a function of the maths problem type, independent of context. This is an important consideration given that the content of the maths curriculum, at least currently within the UK, is varied, thus allowing for the possibility of individual differences in anxiety according to the problem type. It would therefore make sense to consider anxiety as a function of the problem type. The proposed study aimed to develop a new scale to measure maths calculation anxiety that relates to the three core areas of maths within secondary education: statistics and number; number and algebra; and geometry and algebra. Thus, we tested whether maths anxiety differs as a function of the type of maths problem being proposed using confirmatory factor analysis (CFA). Further to this, it was hypothesised that maths calculation anxiety would be related to, but distinct from, general maths anxiety, and thus, a general measure of maths anxiety was also taken.

2. Methods

2.1. Design and Participants. An online, cross-sectional approach was taken in which a series of self-report measures were taken.

2.1.1. Sample One (Exploratory Factor Analysis). Participants consisted of an opportunity sample of 160 (male, $n = 56$; female, $n = 103$; not specified, $n = 1$) undergraduate students (mean age 23.66 years, SD = 7.97) from a university in the Midlands, UK (36.3% psychology; 25.0% joint honours; 21.3% computing; 10.6% maths; 4.4% others; 1.9% unspecified). Students with dyscalculia were not eligible to participate.

2.1.2. Sample Two (Confirmatory Factor Analysis). Participants consisted of a new opportunity sample of 115 (male, $n = 49$; female, $n = 65$; not specified, $n = 1$) undergraduate students (mean age 23.18 years, SD = 6.95) from the same university (24.35% psychology; 19.13% joint honours; 27.83% computing; 3.48% maths; 18.26% others; 6.95% unspecified).

2.2. Measures

2.2.1. Mathematics Calculation Anxiety Scale (MCAS). The authors developed a 36-item self-report measure of maths calculation anxiety, with 12 questions pertaining to each of the three core-areas covered within GCSE maths (algebra, geometry, and statistics). The questions involve general mathematical knowledge and were developed based on the 1MA0/1F (foundation) and 1MA0/1H (higher) Edexcel GCSE papers used in 2013. A five-point Likert-type scale was used, whereby participants responded how anxious they would feel being asked to perform each of the presented problems. A higher score represents a higher level of anxiety (see Appendix for the full scale).

2.2.2. Mathematics Anxiety Scale-UK (MAS-UK). The MAS-UK [15] is a 23-item self-report measure of maths anxiety. Participants are asked to respond using a five-point Likert-type scale how anxious they would feel in a variety of situations involving maths, whereby higher scores representing higher levels of maths anxiety. The scale has excellent internal consistency (Cronbach's alpha = .96) and high test-retest reliability ($r = 0.89$).

2.2.3. Statistics Anxiety Rating Scale (STARS). The STARS [28] is a 51-item self-report measure of statistics anxiety with high internal consistency [29]. The scale is separated into two parts, with the first part consisting of 23 items that relate to situations involving statistics. Participants are asked to indicate, on a five-point scale, how anxious they would feel in each situation. Whilst research has demonstrated both parts comprise an overall multidimensional scale, we included only part A, given the direct relevance of the question and situations to statistics anxiety, as well as the need to minimise the length of the survey.

2.3. Procedure. The survey was administered using Qualtrics online survey software and was advertised via email and the university's research participation system. Demographic questions were presented first, followed by the maths anxiety measures in random order. Ethical considerations were consistent with the guidelines proposed by the British Psychological Society.

3. Results

3.1. Study Sample One

3.1.1. Thirty-Six Item, 3-Factor Model

(1) Descriptive Statistics. The mean maths calculation anxiety was 1.94, with a standard deviation of 0.76. The mean maths anxiety was 2.05, with a standard deviation of 0.67. Maths calculation anxiety displayed a small amount of positive skew ($z = 5.80$), whereas maths anxiety scores were normally distributed ($z = 0.38$).

(2) Internal Consistency of Maths Anxiety Measures. The mean item-total correlation for the MCAS was 0.66 (min = 0.44, max = 0.79). Reliability analysis revealed that Cronbach's alpha for the overall scale was 0.96 and removal of items was not justified. Cronbach's alpha for the MAS-UK was 0.93.

(3) Convergent Validity. General maths anxiety, as measured using the MAS-UK, was significantly positively correlated with maths calculation anxiety, as measured using the MCAS (r (158) = 0.70, $p < 0.001$).

(4) Confirmatory Factor Analysis. Using a maximum likelihood estimator method, a CFA of the original 36-item version of the scale was conducted to determine the fit of the three-factor model. The fit indices were examined and were as follows: chi-square was significant (X^2 (591) = 2010.18, $p < 0.001$), RMSEA = 0.12, SRMR = 0.11, CFI = 0.70, TLI = 0.69, and NFI = 0.63. All the fit indices were outside of values recommended in [30] indicating the three-factor model was a very poor fit to the data.

3.1.2. Twenty-Six Item, 4-Factor Model

(1) Exploratory Factor Analysis (EFA). Principal axis factoring was employed using a direct oblimin rotation. A high Kaiser–Meyer–Olkin measure (KMO = 0.91) indicated that sampling adequacy was met, and very low values in the anti-image correlation matrix provided further evidence that the data were suitable for factor analysis [31]. Several correlations between extracted factors, based on eigenvalues above one, exceeded 0.3, thus indicating nonorthogonality amongst factors and therefore verifying the decision to use a direct oblimin rotation. Initially, using eigenvalues above one as criteria for factor extraction, six factors were extracted. The six factors explained a total of 70.41% of the variance, with 44.45%, 9.10%, 5.93%, 4.60%, 3.38%, and 2.95% of the total variance, being explained by factors one to six, respectively. Factor loadings above 0.3 or 0.4 are considered strong [32]; therefore, the pattern matrix was explored for factor loadings 0.4 or higher. Six items had a factor loading < 0.4 and were subsequently removed. One factor had a single-item loading onto it so the EFA was rerun specifying a five-factor solution. The pattern matrix suggested removal of a further item (factor loading < 0.4) and a factor in which a single item negatively loaded onto it. As such, a four-factor solution was explored, which indicated removal of a further three items, leaving a parsimonious factor structure with 27 items (factor 1, 11 items; factor 2, 5 items; factor 3, 6 items; and factor 4, 5 items). The four factors explained a total of 68.97% of the variance, with 46.55%, 10.25%, 6.70%, and 5.47% of the total variance, being explained by factors one to four, respectively. The mean factor loadings were 0.68, 0.80, 0.65, and 0.63 for factors 1 to 4, respectively.

(2) Factor Labelling. The first factor contained several of the items that were originally proposed to pertain to "geometry," e.g., "find the value of angle X in B" but also included two "algebra" items that are distinct from the rest, e.g., "simplify the expression $a + a + a$." Together these items relate to more abstract maths, and thus, the first factor was labelled *Abstract Maths Anxiety*. The second and third factors separated the original "statistics" items into two clear types of statistics: probability, e.g., "evaluate the probability of getting a sum of 7 when rolling 2 dice," and calculation, e.g., "work out the range of the data in the table above." As such, the second and third factors were labelled *Statistics Probability Anxiety* and *Statistics Calculation Anxiety*, respectively. Finally, factor four contained five items that originally pertained to "algebra" but relate more clearly to numerical calculation, e.g., "work out 1.45×22" and "compare the values of 5/8 and 70%." Therefore, factor four was labelled *Numerical Calculation Anxiety*.

(3) Internal Consistency. Cronbach's alpha for the overall maths calculation anxiety scale was 0.95. Cronbach's alpha for the abstract maths anxiety subscale was 0.94. For the statistics probability subscale, alpha was 0.92, increasing to 0.94 with the removal of one item; consequently, the item was removed. Cronbach's alpha for the statistics calculation anxiety subscale was 0.90, and for the numerical calculation anxiety subscale, it was 0.84.

(4) Descriptive Statistics. The mean maths calculation anxiety of the new 26-item scale was 1.96, with a standard deviation of 0.80. The mean and SD for each subscale were as follows: abstract maths anxiety ($M = 2.24$, SD = 1.07), statistics probability anxiety ($M = 1.79$, SD = 1.01), statistics calculation anxiety ($M = 1.56$, SD = 0.78), and numerical calculation anxiety ($M = 1.97$, SD = 0.84).

(5) Convergent Validity. Maths calculation anxiety was significantly positively correlated with general maths anxiety (r (158) = 0.70, $p < 0.001$). The four subscales of abstract maths anxiety ($r = 0.63$), statistics probability anxiety ($r = 0.39$), statistics calculation anxiety ($r = 0.51$), and numerical calculation anxiety ($r = 0.75$) were all significantly positively correlated with general maths anxiety ($p < 0.001$).

3.2. Study Sample Two

3.2.1. Confirmatory Factor Analysis. A CFA of the 26-item version of the scale was conducted on the new sample to determine the fit of the four-factor model. Fit indices indicated a poor-to-adequate fit: chi-square was significant (X^2 (293) = 725.05, $p < 0.001$), RMSEA = 0.11, SRMR = 0.08, CFI = 0.83, TLI = 0.82, and NFI = 0.76.

3.2.2. Convergent Validity. Maths calculation anxiety was significantly positively correlated with statistics anxiety as measured using the STARS (r (113) = 0.54, $p < 0.001$). Significant positive correlations were also observed with numerical calculation anxiety (r (113) = 0.49, $p < 0.001$), abstract maths anxiety (r (113) = 0.53, $p < 0.001$), statistics probability anxiety (r (113) = 0.35, $p < 0.001$), and statistics calculation anxiety (r (113) = 0.36, $p < 0.001$).

4. Discussion

Using a new, self-report scale, this study aimed to test the existence of maths calculation anxiety as a dimension of the broader maths anxiety construct. Also, we assessed the domain specificity of maths calculation anxiety; that is, whether it is specific to the areas of maths covered in the UK national curriculum for GCSE maths. CFA showed a poor fitting model for the three domains: geometry, algebra, and statistics. EFA indicated a parsimonious, four-factor solution. This maintained the statistics element but separated it into two factors, which we labelled *statistics probability anxiety* and *statistics calculation anxiety*. Interestingly, items that were initially proposed to relate to algebra and geometry loaded onto two factors that we subsequently labelled *abstract maths anxiety* and *numerical calculation anxiety*. The results support previous evidence for the existence of a separate "numerical anxiety" or "arithmetic computation" anxiety component of maths anxiety [20, 22] and also support the existence of anxiety that is specific to more abstract maths (cf. [26]). This is the first study to consider the multidimensionality of maths anxiety at the level of the calculation type. Thus, the findings are interesting from a theoretical perspective; maths calculation anxiety was significantly positively correlated with general maths anxiety but also appears to be specific to the type of maths being performed.

It is important to note that the items related to statistics in the current study are based on typical questions at the GCSE level. Whilst statistics anxiety has been shown to be a separate but related construct to maths anxiety [33], the nature of statistics covered within statistics anxiety scales is quite different to that covered within the GCSE curriculum (and therefore the current scale). For example, the Statistics Anxiety Rating Scale (STARS, [28]) includes items relating to reading a journal article that includes statistical analyses or asking for help with statistical software; these aspects of statistics are usually related to undergraduate study or beyond. Conversely, items on the current scale make reference to typical GCSE problems, such as calculating a mode from a series of numbers or evaluating the probability of getting a head when tossing a coin. Thus, considerations of statistics anxiety need to be made in the context of the population under investigation and the types of problems/situations most relevant to it. Nevertheless, in the present study, we observed significant positive correlations between STARS scores and scores on the maths calculation anxiety subscales.

There are some limitations with the current study that need to be acknowledged. Results cannot be generalised to a non-undergraduate student population given that maths GCSE grade C or above (or equivalent) is typically a minimum entry requirement for most undergraduate degree programmes in the UK. Moreover, many participants were taking courses that included maths, e.g., computing and psychology. As such, it can be assumed that all the participants sampled had a reasonable level of maths ability; this is consistent with the relatively low mean anxiety levels that were observed. Further, courses on which the students in the current study were enrolled varied in terms of the maths and statistics content, but the sample size was insufficient to make group comparisons. Additional sampling is needed of nonstudents and specifically those who have recently taken GCSEs and are about to take GCSEs. This would permit comparison of individuals who have varying maths ability as indicated by existing qualifications and the subject they are currently studying. Furthermore, the relationship between maths calculation anxiety and maths performance could be investigated in the context of subject of study and existing qualifications. In addition, the multidimensionality of maths calculation anxiety remains uncertain; whilst the 26-item version of the Maths Calculation Anxiety Scale provided an improved statistical fit in comparison to the earlier version, the overall fit was only poor to adequate. Finally, we recommend that future research attempts to disentangle anxiety related to the maths problem type and perceived difficulty from anxiety as a function of external context, e.g., pertaining to academic or non-academic situations or test versus non-test situations. The current scale items were derived from test papers based on the UK GCSE national curriculum, including problems with a range of difficulties to ensure the scale is not restricted to individuals with specific maths ability. Nevertheless, it is conceivable that perceived difficulty is subjectively related to the problem type and the relationship of this with anxiety should therefore be investigated.

Despite needing further validation, the Maths Calculation Anxiety Scale appears to be a useful measurement tool in the context of maths calculation specifically. There was sufficient shared variance with general maths anxiety to validate maths calculation anxiety as a related construct; the scale was also shown to have high internal consistency. It appears that a separate tool to measure maths calculation anxiety might have utility in domains where maths calculation is particularly likely, such as within education and in jobs in which calculation is required. It may aid identification of individuals who require additional support and has the potential to be useful in the recruitment process in occupational settings.

Table 1: Questionnaire: Using the scale below (circling the relevant number), how anxious would you feel being asked to . . . . . .

	Not at all	Slightly	A fair amount	Much	Very much
1. Simplify the expression $a + a + a$.	1	2	3	4	5
2. Identify the prime numbers in the list 3, 5, 7, 9, 11, 13, 15, 17, 19, 21.	1	2	3	4	5
3. State Pythagoras' theorem.	1	2	3	4	5
4. Work out the length of the diagonal of rectangle R.	1	2	3	4	5
5. Name the type of the special triangle T.	1	2	3	4	5
6. Name the type of the special quadrilateral P.	1	2	3	4	5
7. Find the area of quadrilateral P and triangle T.	1	2	3	4	5
8. Name and find the area of quadrilateral Q.	1	2	3	4	5
9. Find the value of angle x in A.	1	2	3	4	5
10. Find the value of angle x in B.	1	2	3	4	5
11. Compute the area and circumference of a circle of radius 3.	1	2	3	4	5
12. Evaluate the probability of getting a head when tossing a fair coin.	1	2	3	4	5
13. Evaluate the probability of getting two dots when rolling a fair dice.	1	2	3	4	5
14. Evaluate the probability of getting three or more dots when rolling a fair dice.	1	2	3	4	5
15. Evaluate the probability of getting a sum of 7 when rolling 2 dice.	1	2	3	4	5
16. Compute the average of numbers 11, 13, 15, 18, 21, 14, 30, 13, 12, 13, 12, 17.	1	2	3	4	5
17. Compute the mode of numbers 11, 13, 15, 18, 21, 14, 30, 13, 12, 13, 12, 17.	1	2	3	4	5
18. Compute the range of numbers 11, 13, 15, 18, 21, 14, 30, 13, 12, 13, 12, 17.	1	2	3	4	5
19. Write down the number of students who got 8 marks in the chart below.	1	2	3	4	5
20. Write down the mode for the data in the chart below.	1	2	3	4	5
21. Work out the range of the data in the chart below.	1	2	3	4	5
22. Add the numbers 12, 34, 48 and 66 without a calculator.	1	2	3	4	5
23. Work out 1.45×22.	1	2	3	4	5
24. Compute the sum obtained from 3 coins of 20p and 7 coins of 50p.	1	2	3	4	5
25. Compare the values of 5/8 and 70%.	1	2	3	4	5
26. Convert three and a half hours in minutes.	1	2	3	4	5

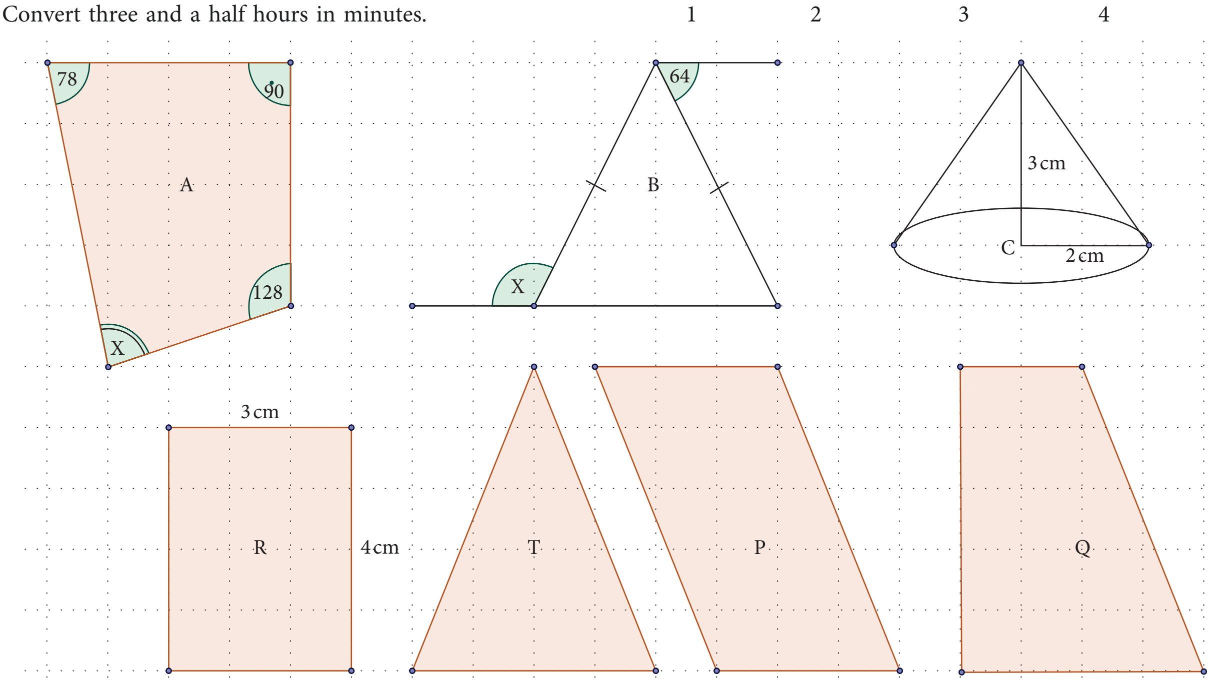
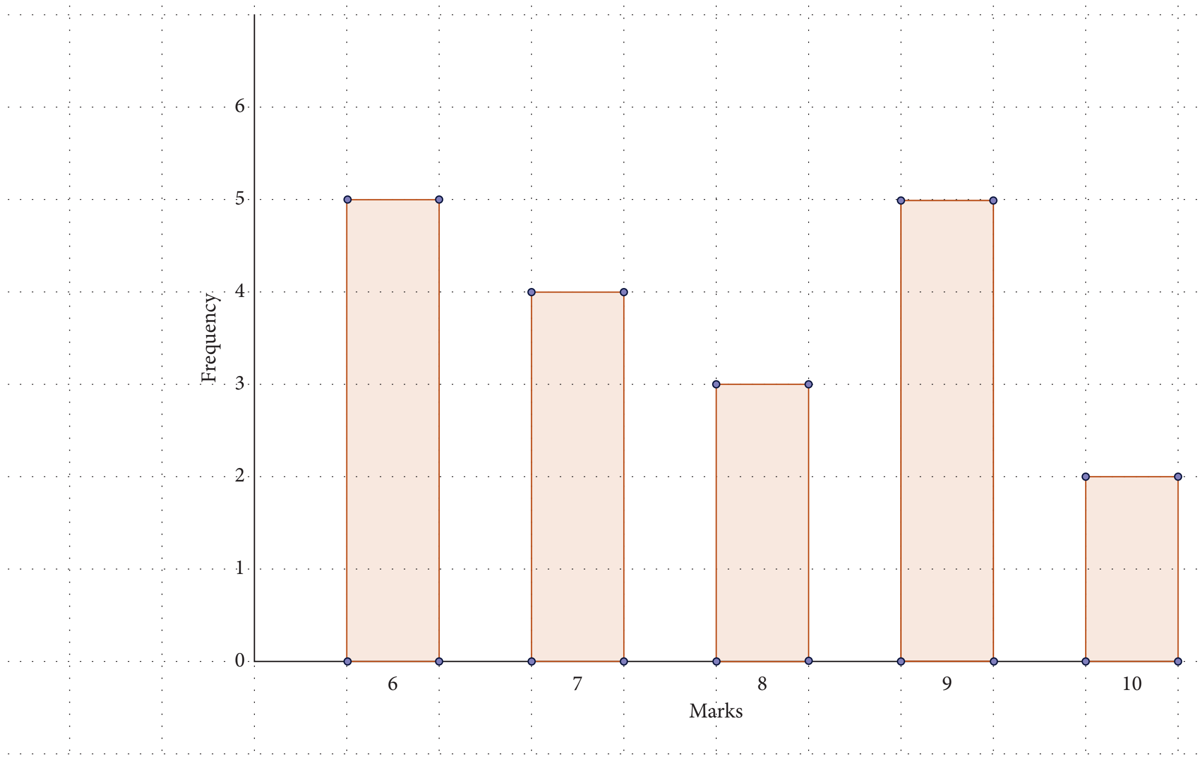


Table 1: Continued.

	Not at all	Slightly	A fair amount	Much	Very much



Appendix

Mathematics Calculation Anxiety Scale

The questionnaire in Table 1 examines your experience of completing maths questions.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

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